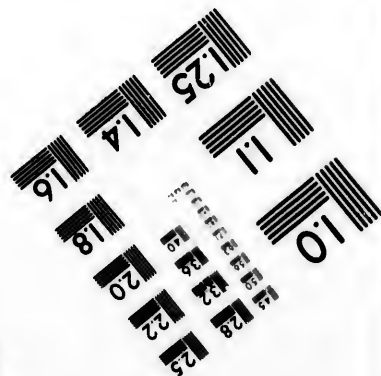
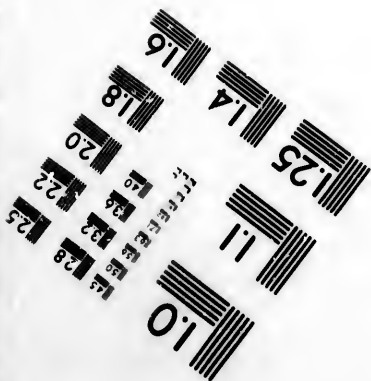
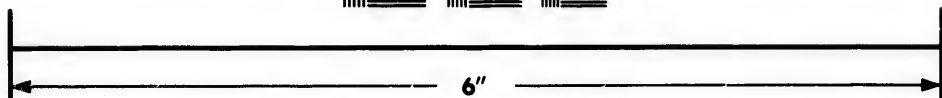
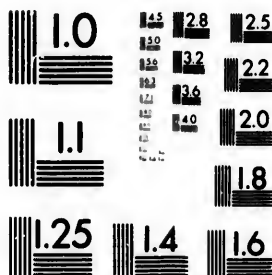


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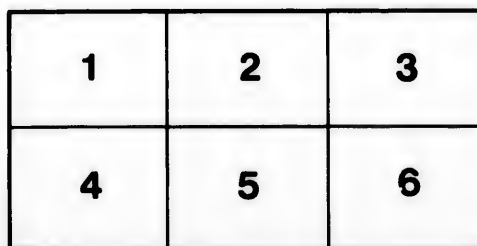
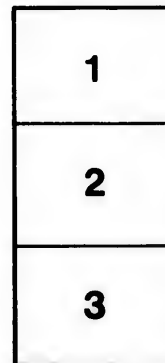
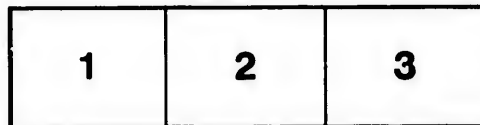
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PROCEEDINGS
OF THE
AMERICAN ACADEMY
OF
ARTS AND SCIENCES.

VOL. XII.
PAPERS READ BEFORE THE ACADEMY.

I.
RESEARCHES IN TELEPHONY.

BY A. GRAHAM BELL.

Presented May 10, 1876, by the Corresponding Secretary.

1. It has long been known that an electro-magnet gives forth a decided sound when it is suddenly magnetized or demagnetized. When the circuit upon which it is placed is rapidly made and broken, a succession of explosive noises proceeds from the magnet. These sounds produce upon the ear the effect of a musical note, when the current is interrupted a sufficient number of times per second. The discovery of "Galvanic Music," by Page,* in 1837, led inquirers in different parts of the world almost simultaneously to enter into the field of telephonic research; and the acoustical effects produced by magnetization were carefully studied by Marrian,† Beatson,‡ Gassiot,§ De la Rive,||

* *C. G. Page*. "The Production of Galvanic Music." *Silliman's Journ.*, 1837, XXXII, p. 396; *Silliman's Journ.*, July, 1837, p. 354; *Silliman's Journ.*, 1838, XXXIII, p. 118; *Bibl. Univ.* (new series), 1839, II, p. 398.

† *J. P. Marrian*. *Phil. Mag.*, XXV, p. 382; *Inst.*, 1845, p. 29; *Arch. de l'Électr.*, V., p. 105.

‡ *W. Beatson*. *Arch. de l'Électr.*, V., p. 197; *Arch. de Sc. Phys. et Nat.* (2d series), II, p. 113.

§ *Gassiot*. See "Treatise on Electricity," by De la Rive, I, p. 300.

|| *De la Rive*. *Treatise on Electricity*, I, p. 300; *Phil. Mag.*, XXXV, p. 422; *Arch. de l'Électr.*, V., p. 200; *Inst.*, 1846, p. 83; *Comptes Rendus*, XX, p. 1287; *Comp. Rend.*, XXII, p. 482; *Pogg. Ann.*, LXXVI, p. 687; *Ann. de Chim. et de Phys.*, XXVI, p. 158.

Matteucci,* Guillemin,† Wertheim,‡ Wartmann,§ Janniar,|| Joule,¶ Laborde,** Legat,†† Reis,‡‡ Poggendorff,§§ Du Moncel,||| Delezenne,¶¶ and others.***

2. In the autumn of 1874, I discovered that the sounds emitted by an electro-magnet under the influence of a discontinuous current of electricity are not due wholly to sudden changes in the magnetic condition of the iron core (as heretofore supposed), but that a portion of the effect results from vibrations in the insulated copper-wires composing the coils. An electro-magnet was arranged upon circuit with an instrument for interrupting the current, — the rheotome being placed in a distant room, so as to avoid interference with the experiment. Upon applying the ear to the magnet, a musical note was clearly perceived, and the sound persisted after the iron core had been removed. It was then much feebler in intensity, but was otherwise unchanged, — the curious crackling noise accompanying the sound being well marked. ●

The effect may probably be explained by the attraction of the coils of the wire for one another during the passage of the galvanic current,

* *Matteucci*. Inst., 1845, p. 315; Arch. de l'Électr., V., 389.

† *Guillemin*. Comp. Rend., XXII., p. 264; Inst., 1846, p. 30; Arch. d. Sc. Phys. (2d series), I., p. 191.

‡ *G. Wertheim*. Comp. Rend., XXII., pp. 336, 544; Inst., 1846, pp. 65, 100; Pogg. Ann., LXVIII., p. 140; Comp. Rend., XXVI., p. 505; Inst., 1848, p. 142; Ann. de Chim. et de Phys., XXIII., p. 302; Arch. d. Sc. Phys. et Nat., VIII., p. 206; Pogg. Ann., LXXVII., p. 43; Berl. Ber., IV., p. 121.

§ *Elie Wartmann*. Comp. Rend., XXII., p. 544; Phil. Mag. (3d series), XXVIII., p. 544; Arch. d. Sc. Phys. et Nat. (2d series), I., p. 419; Inst., 1846, p. 290; Monatscher. d. Berl. Akad., 1846, p. 111.

|| *Janniar*. Comp. Rend., XXIII., p. 319; Inst., 1846, p. 269; Arch. d. Sc. Phys. et Nat. (2d series), II., p. 394.

¶ *J. P. Joule*. Phil. Mag., XXV., pp. 76, 225; Berl. Ber., III., p. 489.

** *Laborde*. Comp. Rend., L., p. 692; Cosmos, XVII., p. 514.

†† *Legat*. Brix. Z. S., IX., p. 125.

‡‡ *Reis*. "Téléphonie." Polytechnic Journ., CLXVIII., p. 185; Böttger's Notizbl., 1863, No. 6.

§§ *J. C. Poggendorff*. Pogg. Ann., XCVIII., p. 192; Berliner Monatsber., 1856, p. 133; Cosmos, IX., p. 49; Berl. Ber., XII., p. 241; Pogg. Ann., LXXXVII., p. 139.

||| *Du Moncel*. Exposé, II., p. 125; also, III., p. 83.

¶¶ *Delezenne*. "Sound produced by Magnetization," Bibl. Univ. (new series), 1841, XVI., p. 406.

*** See London Journ., XXXII., p. 402; Polytechnic Journ., CX., p. 16; Cosmos, IV., p. 43; Glösaener — *Traité général, &c.*, p. 350; Dove-Repert., VI., p. 58; Pogg. Ann., XLIII., p. 411; Berl. Ber., I., p. 144; Arch. d. Sc. Phys. et Nat., XVI., p. 406; Kuhn's Encyclopædia der Physik, pp. 1014-1021.

and the sudden cessation of such attraction when the current is interrupted. When a spiral of fine wire is made to dip into a cup of mercury, so as thereby to close a galvanic circuit, it is well known that the spiral coils up and shortens. Ferguson * constructed a rheotome upon this principle. The shortening of the spiral lifted the end of the wire out of the mercury, thus opening the circuit, and the weight of the wire sufficed to bring the end down again, — so that the spiral was thrown into continuous vibration. I conceive that a somewhat similar motion is occasioned in a helix of wire by the passage of a discontinuous current, although further research has convinced me that other causes also conspire to produce the effect noted above. The extra currents occasioned by the induction of the voltaic current upon itself in the coils of the helix no doubt play an important part in the production of the sound, as very curious audible effects are produced by electrical impulses of high tension. It is probable, too, that a molecular vibration is occasioned in the conducting wire, as sounds are emitted by many substances when a discontinuous current is passed through them. Very distinct sounds proceed from straight pieces of iron, steel, retort-carbon, and plumbago. I believe that I have also obtained audible effects from thin platinum and German-silver wires, and from mercury contained in a narrow groove about four feet long. In these cases, however, the sounds were so faint and outside noises so loud that the experiments require verification. Well-marked sounds proceed from conductors of all kinds when formed into spirals or helices. I find that De la Rive had noticed the production of sound from iron and steel during the passage of an intermittent current, although he failed to obtain audible results from other substances. In order that such effects should be observed, extreme quietness is necessary. The rheotome itself is a great source of annoyance, as it always produces a sound of similar pitch to the one which it is desired to hear. It is absolutely requisite that it should be placed out of earshot of the observer, and at such a distance as to exclude the possibility of sounds being mechanically conducted along the wire.

3. Very striking audible effects can be produced upon a short circuit by means of two Grove elements. I had a helix of insulated copper-wire (No. 23) constructed, having a resistance of about twelve ohms. It was placed in circuit with a rheotome which interrupted the current one hundred times per second. Upon placing the helix to my ear I

* *Ferguson*. Proceedings of Royal Scottish Soc. of Arts, April 9, 1866; Paper on "A New Current Interrupter."

could hear the unison of the note produced by the rheotome. The intensity of the sound was much increased by placing a wrought-iron nail inside the helix. In both these cases, a crackling effect accompanied the sound. When the nail was held in the fingers so that no portion of it touched the helix, the crackling effect disappeared, and a pure musical note resulted.

When the nail was placed inside the helix, between two cylindrical pieces of iron, a loud sound resulted that could be heard all over a large room. The nail seemed to vibrate bodily, striking the cylindrical pieces of metal alternately, and the iron cylinders themselves were violently agitated.

4. Loud sounds are emitted by pieces of iron and steel when subjected to the attraction of an electro-magnet which is placed in circuit with a rheotome. Under such circumstances, the armatures of Morse-sounders and Relays produce sonorous effects. I have succeeded in rendering the sounds audible to large audiences by interposing a tense membrane between the electro-magnet and its armature.* The armature in this case consisted of a piece of clock-spring glued to the membrane. This form of apparatus I have found invaluable in all my experiments. The instrument was connected with a parlor organ, the reeds of which were so arranged as to open and close the circuit during their vibration. When the organ was played the music was loudly reproduced by the telephonic receiver in a distant room. When chords were played upon the organ, the various notes composing the chords were emitted simultaneously by the armature of the receiver.

5. The simultaneous production of musical notes of different pitch by the electric current, was foreseen by me as early as 1870, and demonstrated during the year 1873. Elisha Gray,* of Chicago, and Paul La Cour,† of Copenhagen, lay claim to the same discovery. The fact that sounds of different pitch can be simultaneously produced upon any part of a telegraphic circuit is of great practical importance; for the duration of a musical note can be made to signify the dot or dash of the Morse alphabet, and thus a number of telegraphic messages may be sent simultaneously over the same wire without confusion by making signals of a definite pitch for each message.

6. If the armature of an electro-magnet has a definite rate of oscillation of its own, it is thrown bodily into vibration when the interrup-

* *Elisha Gray*. Eng. Pat. Spec., No. 974. See "Engineer," March 26, 1875.

† *Paul la Cour*. "Telegraphic Journal," Nov. 1, 1875.

tions of the current are timed to its movements. For instance, present an electro-magnet to the strings of a piano. It will be found that the string which is in unison with the rheotome included in the circuit will be thrown into vibration by the attraction of the magnet.

Helmholtz,* in his experiments upon the synthesis of vowel sounds caused continuous vibration in tuning-forks which were used as the armatures of electro-magnets. One of the forks was employed as a rheotome. Platinum wires attached to the prongs dipped into mercury.

The intermittent current occasioned by the vibration of the fork traversed a circuit containing a number of electro-magnets between the poles of which were placed tuning-forks whose normal rates of vibration were multiples of that of the transmitting fork. All the forks were kept in continuous vibration by the passage of the interrupted current. By re-enforcing the tones of the forks in different degrees by means of resonators, Helmholtz succeeded in reproducing artificially certain vowel sounds.

I have caused intense vibration in a steel strip, one extremity of which was firmly clamped to the pole of a U-shaped electro-magnet, the free end overhanging the other pole. The amplitude of the vibration was greatest when the coil was removed from the leg of the magnet to which the armature was attached.

7. All the effects noted above result from rapid interruptions of a voltaic current, but sounds may be produced electrically in many other ways.

The Canon Gotton de Coma,† in 1785, observed that noises were emitted by iron rods placed in the open air during certain electrical conditions of the atmosphere; Beatson ‡ produced a sound from an iron wire by the discharge of a Leyden jar; Gore § obtained loud musical notes from mercury, accompanied by singularly beautiful crispations of the surface during the course of experiments in electrolysis; and Page || produced musical tones from Trevelyan's bars by the action of the galvanic current.

8. When an intermittent current is passed through the thick wires of a Ruhmkorff's coil, very curious audible effects are produced by the

* *Helmholtz*. Die Lehre von dem Tonempfindungen.

† See "Treatise on Electricity," by De la Rive, I., p. 300.

‡ *Ibid*.

§ *Gore*. Proceedings of Royal Society, XII., p. 217.

|| *Page*. "Vibration of Trevelyan's bars by the galvanic current." *Silliman's Journal*, 1850, IX., pp. 105-108.

currents induced in the secondary wires. A rheotome was placed in circuit with the thick wires of a Ruhmkorff's coil, and the fine wires were connected with two strips of brass (A and B), insulated from one another by means of a sheet of paper. Upon placing the ear against one of the strips of brass, a sound was perceived like that described above as proceeding from an empty helix of wire during the passage of an intermittent voltaic current. A similar sound, only much more intense, was emitted by a tin-foil condenser when connected with the fine wires of the coil.

One of the strips of brass, A (mentioned above), was held closely against the ear. A loud sound came from A whenever the slip B was touched with the other hand. It is doubtful in all these cases whether the sounds proceeded from the metals or from the imperfect conductors interposed between them. Further experiments seem to favor the latter supposition. The strips of brass A and B were held one in each hand. The induced currents occasioned a muscular tremor in the fingers. Upon placing my forefinger to my ear a loud crackling noise was audible, seemingly proceeding from the finger itself. A friend who was present placed my finger to his ear, but heard nothing. I requested him to hold the strips A and B himself. He was then distinctly conscious of a noise (which I was unable to perceive) proceeding from his finger. In these cases a portion of the induced currents passed through the head of the observer when he placed his ear against his own finger; and it is possible that the sound was occasioned by a vibration of the surfaces of the ear and finger in contact.

When two persons receive a shock from a Ruhmkorff's coil by clasping hands, each taking hold of one wire of the coil with the free hand, a sound proceeds from the clasped hands. The effect is not produced when the hands are moist. When either of the two touches the body of the other a loud sound comes from the parts in contact. When the arm of one is placed against the arm of the other, the noise produced can be heard at a distance of several feet. In all these cases a slight shock is experienced so long as the contact is preserved. The introduction of a piece of paper between the parts in contact does not materially interfere with the production of the sounds, while the unpleasant effects of the shock are avoided.

When a powerful current is passed through the body, a musical note can be perceived when the ear is closely applied to the arm of the person experimented upon. The sound seems to proceed from the muscles of the fore-arm and from the biceps muscle. The musical note is the unison of the rheotome employed to interrupt the primary

circuit. I failed to obtain audible effects in this way when the pitch of the rheotome was high. Elisha Gray* has also produced audible effects by the passage of induced electricity through the human body. A musical note is occasioned by the spark of a Ruhmkorff's coil when the primary circuit is made and broken sufficiently rapidly. When two rheotomes of different pitch are caused simultaneously to open and close the primary circuit, a double tone proceeds from the spark.

9. When a voltaic battery is common to two closed circuits, the current is divided between them. If one of the circuits is rapidly opened and closed, a pulsatory action of the current is occasioned upon the other.

All the audible effects resulting from the passage of an intermittent current can also be produced, though in less degree, by means of a pulsatory current.

10. When a permanent magnet is caused to vibrate in front of the pole of an electro-magnet, an undulatory or oscillatory current of electricity is induced in the coils of the electro-magnet, and sounds proceed from the armatures of other electro-magnets placed upon the circuit. The telephonic receiver referred to above (par. 4), was connected in circuit with a single-pole electro-magnet, no battery being used. A steel tuning-fork which had been previously magnetized was caused to vibrate in front of the pole of the electro-magnet. A musical note similar in pitch to that produced by the tuning-fork proceeded from the telephonic receiver in a distant room.

11. The effect was much increased when a battery was included in the circuit. In this case, the vibration of the permanent magnet threw the battery-current into waves. A similar effect was produced by the vibration of an unmagnetized tuning-fork in front of the electro-magnet. The vibration of a soft iron armature, or of a small piece of steel spring no larger than the pole of the electro-magnet in front of which it was placed, sufficed to produce audible effects in the distant room.

12. Two single-pole electro-magnets, each having a resistance of ten ohms, were arranged upon a circuit with a battery of five carbon elements. The total resistance of the circuit, exclusive of the battery, was about twenty-five ohms. A drum-head of gold-beater's skin, seven centimetres in diameter, was placed in front of each electro-magnet, and a circular piece of clock-spring, one centimetre in diameter, was glued to the middle of each membrane. The telephones so constructed were placed in different rooms. One was retained in

* Elisha Gray. Eng. Pat. Spec., No. 2646, see "Engineer," Aug. 14, 1874.

the experimental room, and the other taken to the basement of an adjoining house.

Upon singing into the telephone, the tones of the voice were reproduced by the instrument in the distant room. When two persons sang simultaneously into the instrument, two notes were emitted simultaneously by the telephone in the other house. A friend was sent into the adjoining building to note the effect produced by articulate speech. I placed the membrane of the telephone near my mouth, and uttered the sentence, "Do you understand what I say?" Presently an answer was returned through the instrument in my hand. Articulate words proceeded from the clock-spring attached to the membrane, and I heard the sentence: "Yes; I understand you perfectly."

The articulation was somewhat muffled and indistinct, although in this case it was intelligible. Familiar quotations, such as, "To be, or not to be; that is the question." "A horse, a horse, my kingdom for a horse." "What hath God wrought," &c., were generally understood after a few repetitions. The effects were not sufficiently distinct to admit of sustained conversation through the wire. Indeed, as a general rule, the articulation was unintelligible, excepting when familiar sentences were employed. Occasionally, however, a sentence would come out with such startling distinctness as to render it difficult to believe that the speaker was not close at hand. No sound was audible when the clock-spring was removed from the membrane.

The elementary sounds of the English language were uttered successively into one of the telephones and the effects noted at the other. Consonantal sounds, with the exception of L and M, were unrecognizable. Vowel-sounds in most cases were distinct. Diphthongal vowels, such as *a* (in ale), *o* (in old), *i* (in isle), *ow* (in now), *oy* (in boy), *oor* (in poor), *oor* (in door), *ere* (in here), *ere* (in there), were well marked.

Triphthongal vowels, such as *ire* (in fire), *our* (in flour), *ower* (in mower), *ayer* (in player), were also distinct. Of the elementary vowel-sounds, the most distinct were those which had the largest oral apertures. Such were *a* (in far), *aw* (in law), *a* (in man), and *e* (in men).

13. Electrical undulations can be produced directly in the voltaic current by vibrating the conducting wire in a liquid of high resistance included in the circuit.

The stem of a tuning-fork was connected with a wire leading to one of the telephones described in the preceding paragraph. While the tuning-fork was in vibration, the end of one of the prongs was dipped

into water included in the circuit. A sound proceeded from the distant telephone. When two tuning-forks of different pitch were connected together, and simultaneously caused to vibrate in the water, two musical notes (the unisons respectively of those produced by the forks) were emitted simultaneously by the telephone.

A platinum wire attached to a stretched membrane, completed a voltaic circuit by dipping into water. Upon speaking to the membrane, articulate sounds proceeded from the telephone in the distant room. The sounds produced by the telephone became louder when dilute sulphuric acid, or a saturated solution of salt, was substituted for the water. Audible effects were also produced by the vibration of plumbago in mercuric, in a solution of bichromate of potash, in salt and water, in dilute sulphuric acid, and in pure water.

14. Sullivan* discovered that a current of electricity is generated by the vibration of a wire composed partly of one metal and partly of another; and it is probable that electrical undulations were caused by the vibration. The current was produced so long as the wire emitted a musical note, but stopped immediately upon the cessation of the sound.

15. Although sounds proceed from the armatures of electro-magnets under the influence of undulatory currents of electricity, I have been unable to detect any audible effects due to the electro-magnets themselves. An undulatory current was passed through the coils of an electro-magnet which was held closely against the ear. No sound was perceived until a piece of iron or steel was presented to the pole of the magnet. No sounds either were observed when the undulatory current was passed through iron, steel, retort-carbon, or plumbago. In these respects an undulatory current is curiously different from an intermittent one. (See par. 2.)

16. The telephonic effects described above are produced by three distinct varieties of currents, which I term respectively intermittent, pulsatory, and undulatory. *Intermittent currents* are characterized by the alternate presence and absence of electricity upon the circuit; *Pulsatory currents* result from sudden or instantaneous changes in the intensity of a continuous current; and *undulatory currents* are produced by gradual changes in the intensity of a current analogous to the changes in the density of air occasioned by simple pendulous vibrations. The varying intensity of an undulatory current can be

* *Sullivan*. "Currents of Electricity produced by the vibration of Metals." *Phil. Mag.*, 1845, p. 261; *Arch. de l'Électr.*, X., p. 480.

represented by a sinusoidal curve, or by the resultant of several sinusoidal curves.

Intermittent, pulsatory, and undulatory currents may be of two kinds, — *voltaic*, or *induced*; and these varieties may be still further discriminated into *direct* and *reversed* currents; or those in which the electrical impulses are all positive or negative, and those in which they are alternately positive and negative.

Telephonic effects can be produced by means of currents of electricity, which are	Intermittent.	{ Voltaic.	{ Direct (See par. 1, 2, 3, 4, 5, 6).
		{ Induced.	{ Reversed.
	Pulsatory.	{ Voltaic.	{ Direct.
		{ Induced.	{ Reversed (See par. 8).
	Undulatory.	{ Voltaic.	{ Direct (See par. 9).
		{ Induced.	{ Reversed.
		{ Voltaic.	{ Direct (See par. 11, 12, 13, 15).
		{ Induced.	{ Reversed.
			{ Direct.

17. In conclusion, I would say that the different kinds of currents described above may be studied optically by means of König's manometric capsule.* The instrument, as I have employed it, consists simply of a gas-chamber closed by a membrane to which is attached a piece of clock-spring. When the spring is subjected to the attraction of an electro-magnet, through the coils of which a "telephonic" current of electricity is passed, the flame is thrown into vibration.

I find the instrument invaluable as a rheometer, for an ordinary galvanometer is of little or no use when "telephonic" currents are to be tested. For instance, the galvanometer needle is insensitive to the most powerful undulatory current when the impulses are reversed, and is only slightly deflected when they are direct. The manometric capsule, on the other hand, affords a means of testing the amplitude of the electrical undulations; that is, of deciding the difference between the maximum and minimum intensity of the current.

* König. "Upon Manometric Flames," Phil. Mag., 1873, XLV., No. 297, 298.

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